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Additional Applications of the Electrical Conductivity Velocity Meter

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Prepared by A. E. FUHS

Prepared for DEPUTY COMMANDER AEROSPACE SYSTEMS
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
Inglewood, California

PHYSICAL RESEARCH LABORATORY • AEROSPACE CORPORATION
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ADDITIONAL APPLICATIONS OF THE ELECTRICAL CONDUCTIVITY VELOCITY METER

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ABSTRACT

By using the directional sensitivity of the electrical conductivity instrument with the E-lamination geometry, it is possible to measure the direction of the flow of a conducting gas. If only one coil set is used, a complex calibration procedure is necessary; however, by using two coil sets the flow angle becomes a function only of the ratio of the two signals.

The second application involves the axial flow electrical conductivity transducer. In order to determine the relative contribution of different ablating materials to the electron density in the plasma sheath, a standard test is proposed. Tubes of various ablating materials are manufactured. A measurement of electrical conductivity-velocity product (σu) is obtained for each material under identical plasma source conditions. Comparison of the σu values may indicate, in a relative manner, the influence of the ablating material.

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FIGURES

I. INTRODUCTION

Three transducers have been developed for measuring the average σu (σ is electrical conductivity and u is velocity) of a flowing plasma stream. One transducer, which appears in Figure 1, is developed for flight aboard a re-entry vehicle.[1, 2, 3] The other two transducers, which are shown in Figures 2 and 3, can be used with plasma arc jet facilities.[4] This brief note outlines two additional applications for these meters which yield useful information.

II. FLOW DIRECTION INDICATOR

A. Ideal Transducer

The signal induced in the sensing coil depends not only on the value of σu, but on the angle of the flow relative to the transducer. If one meter is used, it is difficult to extract the flow angle θ since the signal is a function of σu and θ. However, if two transducers are used, as shown in Figure 4, the dependence on σ and u is removed. The voltage induced in coil set (1) is ideally

$$e_1 = e_o \cos(\alpha - \theta) \quad , \tag{1}$$

and for coil set (2):

$$e_2 = e_o \cos(\alpha + \theta) \tag{2}$$

where e_o is signal for zero flow angle. The signal e_o is a function of σ and u. In order to obtain θ without the use of the two sets of coils, it is necessary to know e_o. The ratio of signals e_2/e_1, which is symbolized as R, is a function of α and θ only. Manipulation shows that

$$\theta = \arctan\left(\frac{1 - R}{1 + R}\,\frac{1}{\tan\alpha}\right) \quad . \tag{3}$$

The angle α is a design parameter which can be optimized with consideration for departures from the ideal transducer.

B. Departures from Ideal Transducer

Use of the two coil sets has effectively eliminated dependence of θ on σ and u. An ideal transducer gives signals as defined by Equations 1 and 2. However, a real transducer will have a signal

$$e = e_o \left[\cos(\alpha \pm \theta) + f(\alpha \pm \theta)\right] + n \tag{4}$$

In Equation 4, n represents the null signal which is the signal in the absence of plasma flow. The term $f(\alpha \pm \theta)$ gives the small departure from the cosine behavior. Experiments indicate that for $0 \leqslant \alpha + \theta \leqslant 40^{\circ}$, $f(\alpha \pm \theta)/\cos(\alpha \pm \theta)$ is less than a few per cent. Neglecting $f(\alpha \pm \theta)$, the signal ratio becomes

$$R = \frac{\cos(\alpha + \theta) + (n_2/e_o)}{\cos(\alpha - \theta) + (n_1/e_o)} \quad . \tag{5}$$

To remove the dependence of R on σ and u, it is essential that n_1/e_o and n_2/e_o should be much less than unity.

III. STANDARD TEST FOR ELECTRICAL PROPERTIES OF ABLATING MATERIAL

The plasma sheath surrounding a re-entry vehicle can cause a disruption of communications. Presence of the ionized gas may enhance the radar cross section. The chemical species which comprise the plasma sheath are those which can be derived from the elements of air O and N and elements of ablating material; e.g., C, H, N, and O. The ablating material can have an influence on the electrical properties of the sheath. A particular ablating material may contribute more ions and electrons, and hence greater attenuation

of electromagnetic waves, than another ablating material. A test for a proposed ablating material is to use the axial flow meter shown in Figure 2. Tubes of various ablation materials are manufactured. A measurement of σu is obtained for each material under identical source conditions for the plasma flow. Comparison of the σu values indicates, in a relative manner, the extent to which the ablating material may influence the plasma sheath properties.

Figure 1. An electrical conductivity meter developed for re-entry experiments.

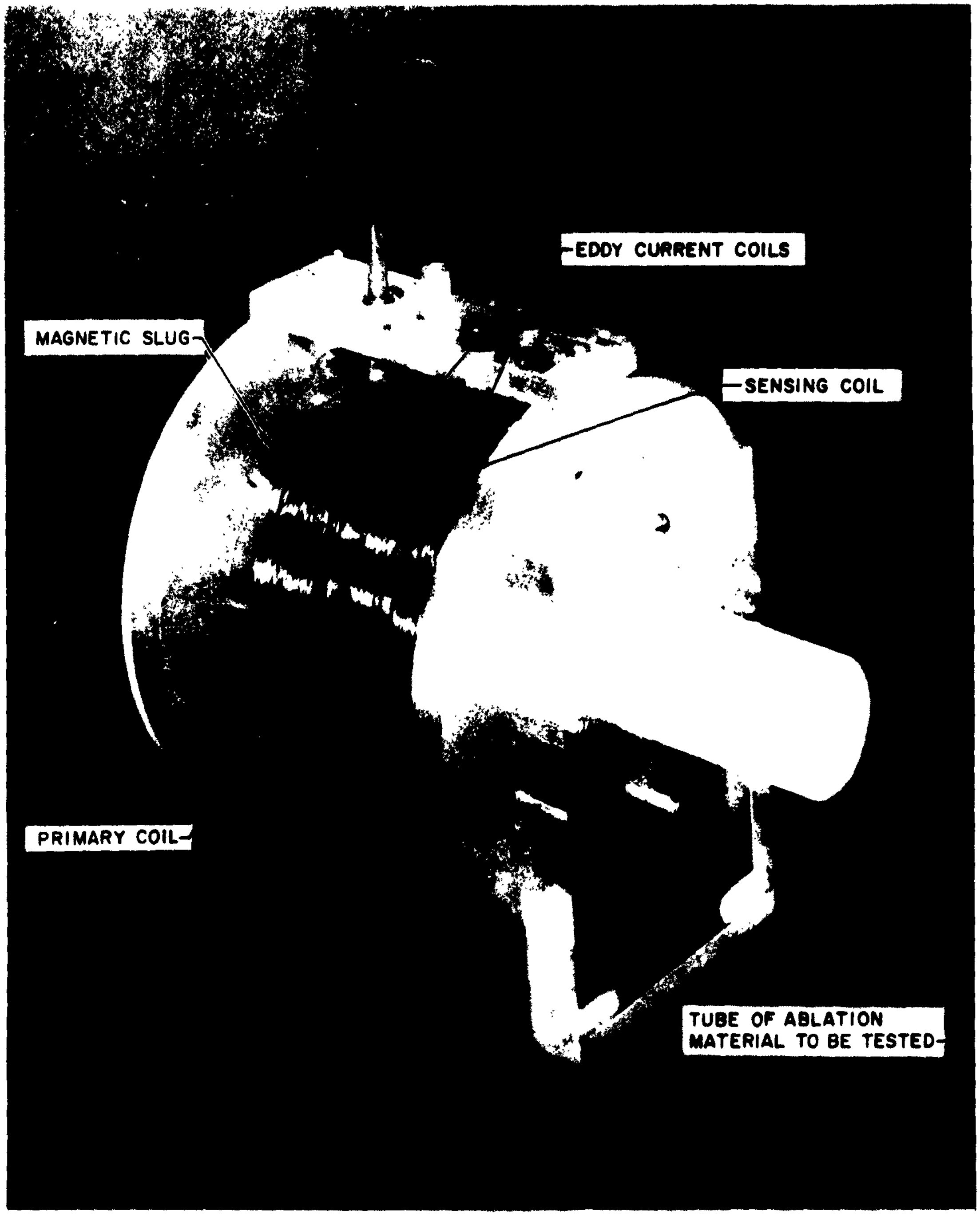

Figure 2. The tube can be changed.

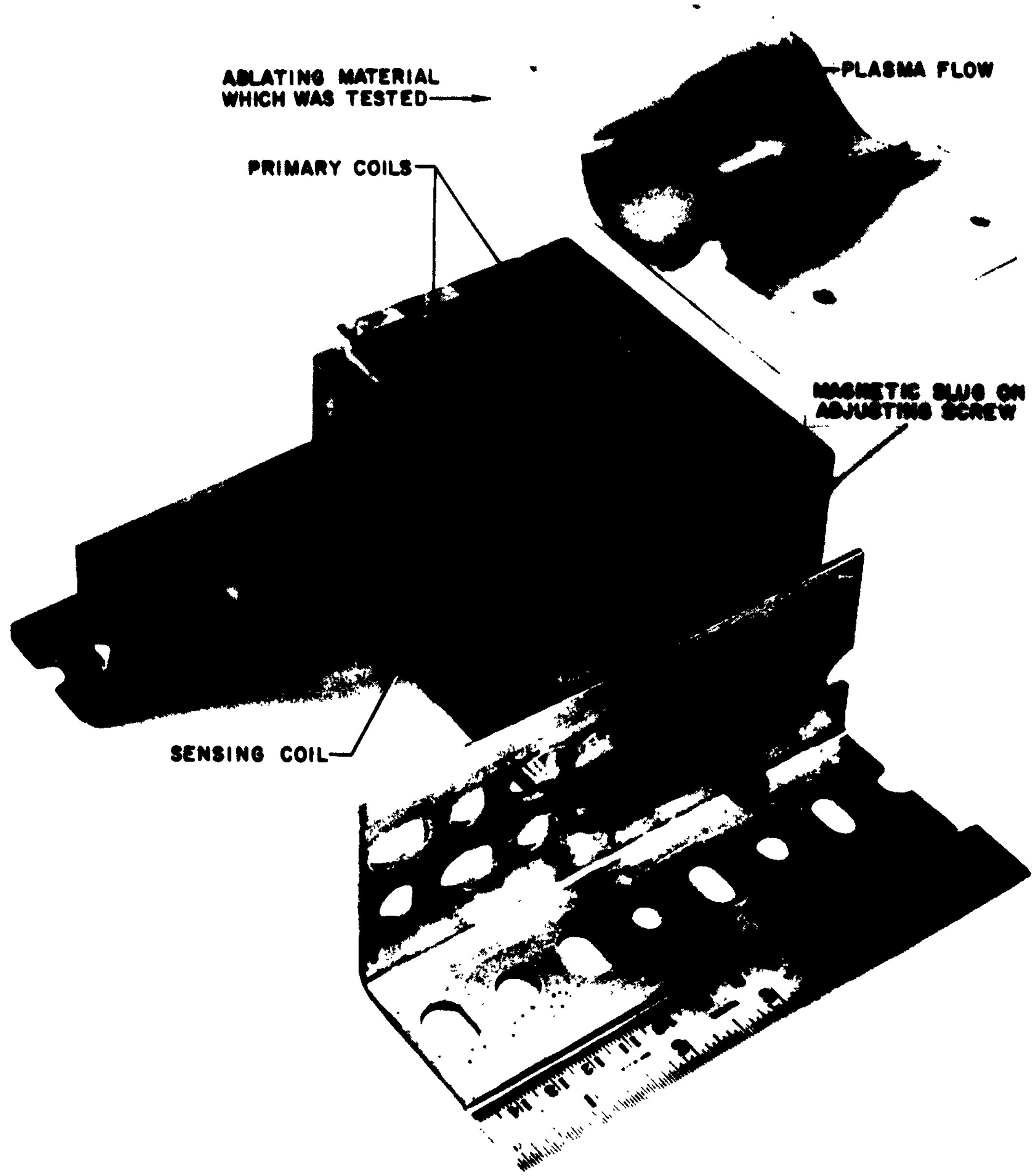

Figure 3. The plasma jet impinges on the ablating material which covers the meter face.

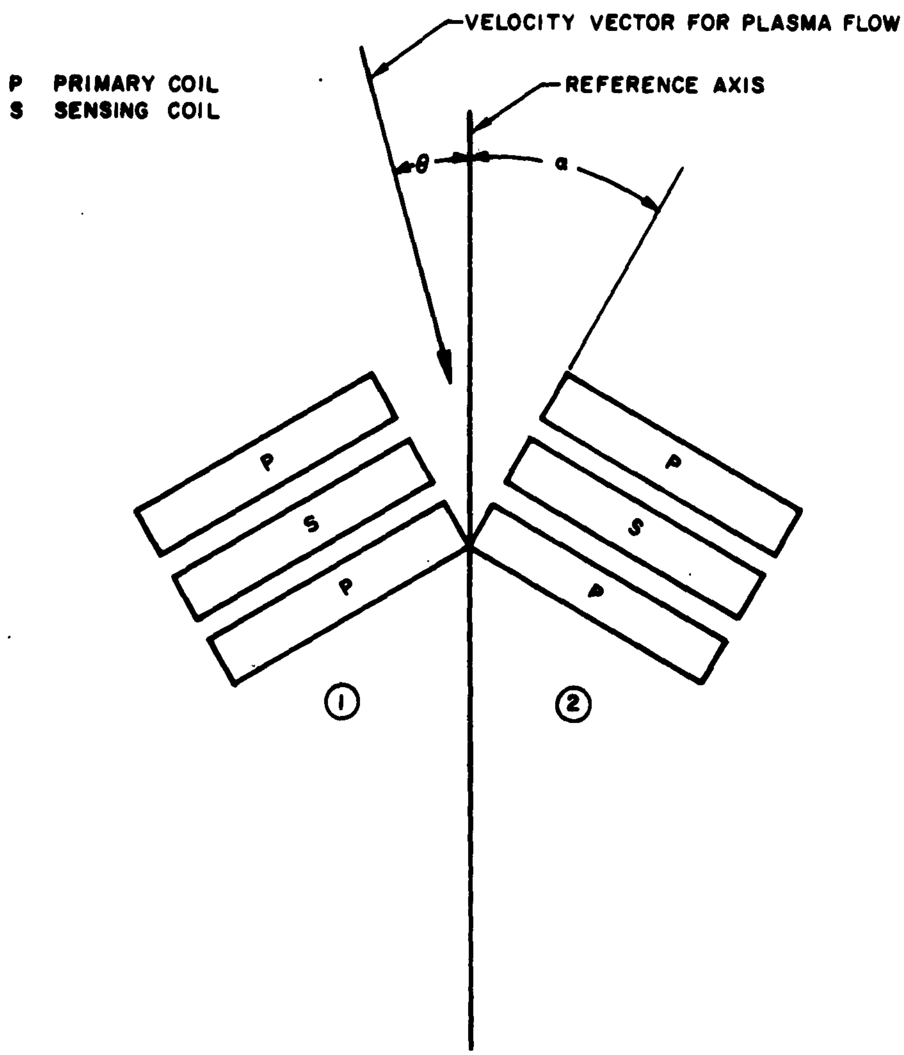

Figure 4. The geometry of the flow angle transducer. The plasma flow is parallel to the plane of the paper. The coil sets would be similar to the meter shown in Figure 3.

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By using the directional sensitivity of the electrical conductivity instrument with the E-lamination geometry, it is possible to measure the direction of the flow of a conducting gas. If only one coil set is used, a complex calibration procedure is necessary; however, by using two coil sets the flow angle becomes a function only of the ratio of the two signals.

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